

Optimal DC Link Topologies for Best Utilization of Switch Modules



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Agenda



- Introduction and Corporate Overview
 - Critical Customer Partnership Program
- SBE Power Ring Film Capacitor™
- Optimized DC Link Topology
- New: Prototype Bus Capabilities
- Summary
- Questions

SBE Corporate Overview



Established: 1945 as **Sprague Electric**; SBE formed in 1985 with film cap lines purchased from Sprague

Locations: Headquarters, Manufacturing and R&D Center: Barre, Vermont
Application Engineering and Sales: Colorado and China

Facilities: 53,000 square feet new facility with capacity for over 100,000 Vehicles
China: engineering and assembly – 5,000 square feet

Distributors: Future Electronics – worldwide
Richwood–China and Hong-Kong
Flux Interconnect – Korea
Jin Zon Enterprise- Taiwan
Pulse Power & Measurement - UK

Ownership: Privately Held Corporation

Markets: Transportation, Alternative Energy,
Medical/Laser, Military, UPS, HVDC, STATCOM

Key Customers: TM4 - PEPS, ZF, Solectria Renewables,
Candela Laser, Vertiv, Caterpillar,
GE, Siemens, Dynapower
Danfoss, Hofer



Vermont Facility



SBE Roadmap



DOE SBIR and Recover Act Funding plus investment

Next generation polypropylene film capacitors for 105C coolant automotive applications

Power Ring Capacitor with optimized form factor = best performance for ANY film



State of the Art 53,000 square foot factory in Barre, Vermont

High performance capacitor design, simulation, and testing

Unique Proprietary winding technology

Advanced packaging

New Product: Integrated capacitor/bus



Critical Customer Partner Program



- SBE is overwhelmed with requests for highly customized cap/bus designs
- In December 2018 we implemented our Critical Customer Partner Program
 - Various membership levels available to guarantee engineering support and production capacity
 - Down payment required to lock in project schedule
 - Lead time to start new programs for non-partners is 8-12 weeks

The Power Ring Advantage



- Film is film to all capacitor vendors - everyone has access to the same film suppliers
- SBE has targeted the annular form factor to provide the best possible performance
 - Significant investment in proprietary winding technology
 - Patent coverage for key technology aspects
 - Integration of polymer winding with copper terminals
 - Advanced design and simulation capabilities
 - Understand performance at the system integration level
- Industry second source – Rogers Corp.

Key Technology Factors



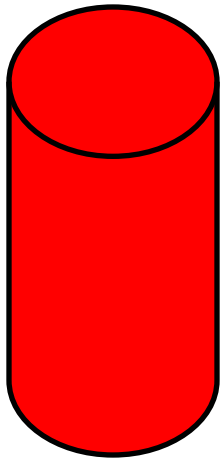
- Large monolithic winding for lower cost
 - Better performance than a bank of smaller parts
- Short current path provides very low ESR
 - Low losses
- Large thermal cross section area provides efficient heat removal
 - Minimal hot spot temperature rise
 - Highest possible current rating for given capacitance
 - Best performance for ANY film

Key Technology Factors



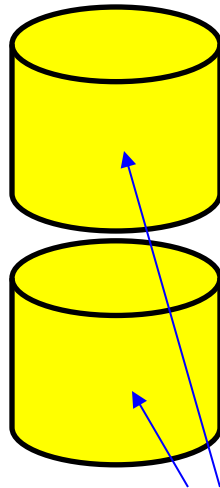
- Maximize $A/\mu\text{F}$ so $\mu\text{F}/\text{kW}$ is defined by control limit not capacitor current rating

Typical "Can"



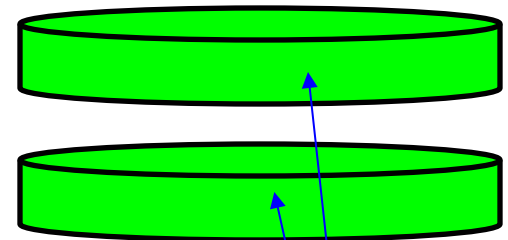
$$\Delta T = I^2 \times \text{ESR} \times R_T$$

Cut in Half



ESR reduced by 2x
 R_T reduced by 2x

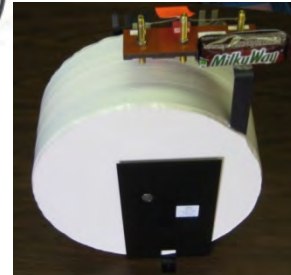
Narrow film wound into a "Platter"



ESR reduced by 10x
 R_T reduced by 10x

SBE Next Generation Film Capacitor Solutions

Power Ring Film Capacitor™
is a Building Block for
Enabling Technology at
the SYSTEM Level



Pulse caps with
excellent
reliability and
peak current
rating



AC Filter – Oil free patented
segmentation eliminates
catastrophic failures



DC Link – Integrated cap/bus for high
performance traction drive



DC Link – integrated cap/bus for increased
power density in alternative energy and
network power



Introduction to DC Link



- Traditional inverter design takes the approach of adding μF until the capacitor bank can handle current to achieve the required life
 - This is not effective in terms of power density, cost, or volume
- Working voltage and switching speed (efficiency) limited by the ESL of the DC link
 - Interconnection between DC link capacitor and switch module is limiting factor

SBE DC Link Technology



- Objective: Provide an optimized DC link such that customer can extract maximum value from investment in switch modules
- This is achieved as follows:
 - Provide highest possible Ampere/ μ F rating such that capacitance is defined by control limit rather than capacitor life (minimize μ F/kW)
 - Integrated cap/bus to provide the lowest possible inductance at switch module inputs

SBE DC Link Technology



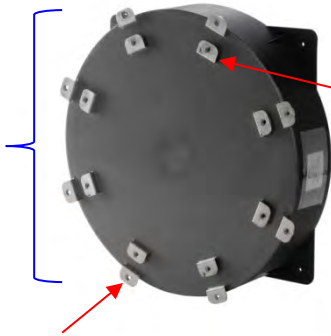
- Packaging and integration of the capacitors is critical for best performance
 - Optimize terminal configuration for capacitor to improve magnetic flux cancellation
 - Integrate capacitor(s) directly onto the bus structure as “surface mount” devices
 - Eliminate redundant conductor layers
 - Improve connection geometry from cap/bus to switch module(s) = optimal **TOPOLOGY**

SBE DC Link Topology



Example: 777A104 Test Kit (3000uF at 1100V)

Start with
700D590
discrete
capacitor



Remove bottom terminal from “discrete” capacitor and let bus conductor be the terminal (reduce copper and path length)

Keep top “crown” terminal for low ESL



Coaxial “through-hole” connections to half-bridge

Integrated cap/bus assembly (UL)

Locate DC input tabs to optimize current distribution



Enabling Ecosystem



- Next generation inverters must improve power density and efficiency
 - This requires an enabling “ecosystem” to support the semiconductor switches
 - Gate driver
 - Bus bar
 - DC link capacitor
 - Cooling
- SBE integrated cap/bus topology forms the foundation

Enabling Ecosystem



- **Advanced Silicon**
 - Higher operating voltage
 - Faster switching
 - Massive paralleling of switch modules to achieve very high current
- **Silicon Carbide**
 - Higher operating voltage
 - Higher operating temperature
 - Very fast switching
 - Parallel modules needed to get to medium current

Enabling Ecosystem



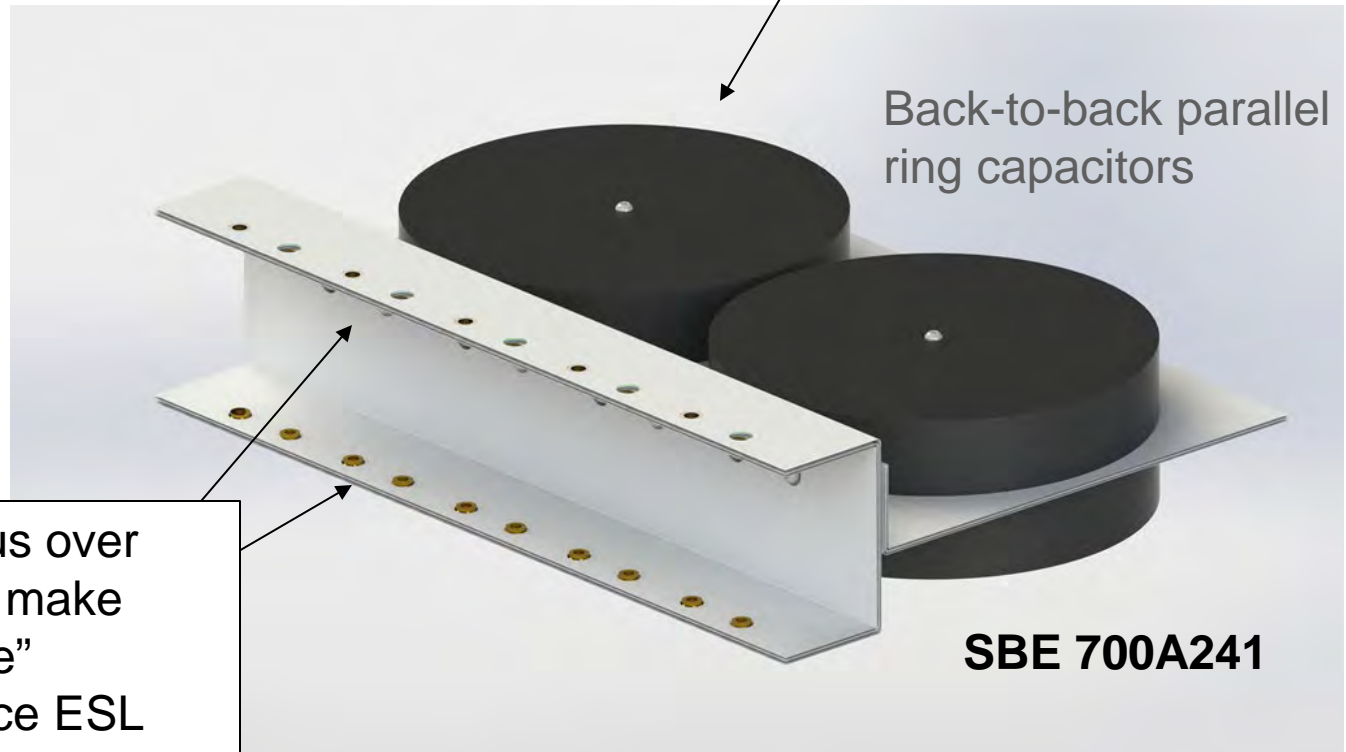
- The enabling DC link requires the following ingredients
 - Optimized topology and bus structure
 - Very low commutation inductance
 - Paralleling of switch modules (balancing)
 - Very low capacitor losses
 - Higher capacitor working voltages
 - Increasing capacitor temperatures

Paralleling Modules



DC Link for Paralleling Infineon XHP™ Modules

Add additional rows of 4x windings as needed for system mF value (e.g. weak grid)



Back-to-back parallel
ring capacitors

SBE 700A241

Extend laminated bus over
switch modules and make
coaxial “through hole”
connections to reduce ESL
($< 10\text{nH}$ seen by modules)



Paralleling Modules



Paralleling Modules



- Infineon double pulse testing demonstrates current balancing is better than 5% with 10x modules in parallel
- The use of two-sided cooling plate for modules complicates topology => multiple bus components needed
 - “C” bus connected to main cap/bus with multiple parallel coaxial contacts

Higher Working Voltage



- Example: HVDC and SVC applications
 - 2.8kV and up
 - Customers are now looking to reduce all component losses
- Power density = capacitance density
 - Thinner film to manage capacitor volume
 - Lighter metallization to support higher operating stresses
 - SBE form factor can actually reduce ESR while taking this approach

Higher Working Voltage

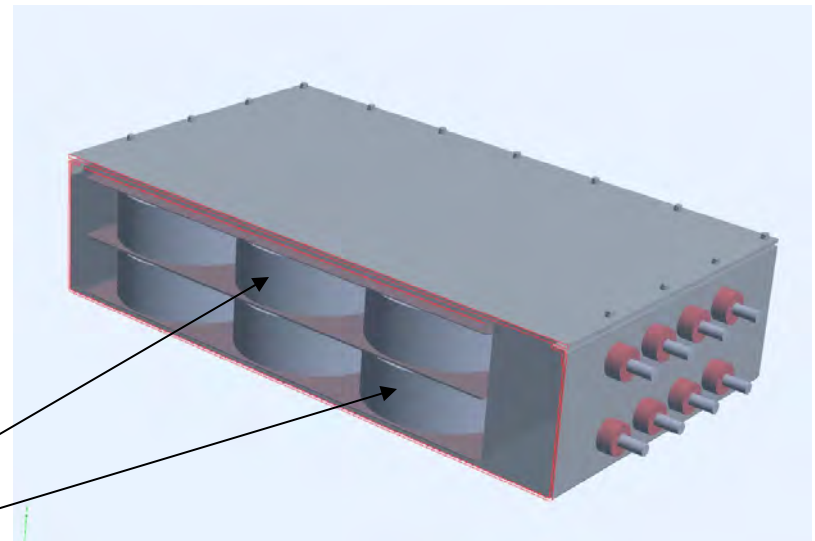


The traditional “box cap”



Improved “box cap” with lower losses using SBE rings

- Dissipation losses are the same
- Electrode losses are reduced by up to 3x



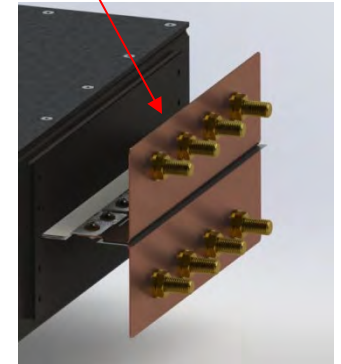
Array of ring capacitors connected to bus plates with patented technology

Topology

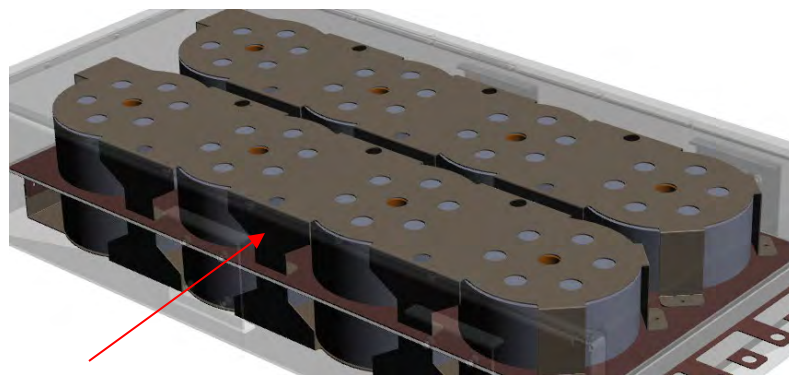


On display at booth 930

Universal bus with adapters allows immediate use with existing hardware with later upgrade



Support ESL migration roadmap



Low ESL "crown terminal"

Optimized: Mount capacitors "back to back" on low-inductance bus and transition bus out to of case to the switch modules

Higher Temperature



- SBE Collaboration with DuPont Teijin Films launched in May 2017
 - SBE is exclusive supplier of PEN HV film for capacitor sizes compatible with Power Ring
- Excellent quality achieved with SBE's unique winding equipment
- Enables operation beyond 125C
 - Dielectric strength and self-healing comparable to polypropylene
 - PEN HV windings can readily be utilized for existing DC link designs

New: Prototype Bus Capabilities



- The bus industry currently has prototype lead times ranging from 12 to 25 weeks
 - This does not support rapid customer validation of SBE cap/bus technology
- SBE will be implementing in-house prototype bus fabrication in Q2 2019 for critical customer partners
- We will continue to maintain strong relationship with industry leading bus vendors for production

Summary



- Lowest $\mu\text{F}/\text{kW}$ rating
 - Smallest size and lowest cost
- SBE DC link is a key component of the enabling “ecosystem” for advanced Si and SiC applications
 - Critical for paralleling of modules
- Integrated cap/bus for low ESL
 - Allows for much greater switch utilization
- SBE is bringing prototype bus fabrication on line in Q2 2019
- Please stop by our booth (930) and discuss your application with the SBE team